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*EXPERIMENTS WITH PHOSPHATE FERTILIZERS IN MINNESOTA

By F. J. Alway, Division of Soils

PHOSPHATES PROFITABLE IN MANY STATES

Phosphates have been found highly profitable on most of the soils of Illinois, Indiana, Ohio, and other states to the east and southeast of Minnesota, especially in combination with farm manures. In western Europe enormous quantities of these fertilizers have long been used, while even on the comparatively virgin soils of Australia a light dressing of acid phosphate has been found so remunerative that it is now used on millions of acres of wheat every year.

DIFFERENT KINDS OF PHOSPHATE FERTILIZERS

The forms of phosphate used in different countries depend somewhat upon the character of the soils to which they are to be applied, but chiefly upon the relative prices. Thus, basic slag is comparatively high priced in the United States while acid phosphate and raw rock phosphate are relatively cheap. Most experiment stations recommend acid phosphate applied once or twice in the course of a rotation, but the Illinois experiment station advocates the use of the cheaper raw rock phosphate ground very fine and applied as a very heavy dressing at much less frequent intervals. The phosphoric acid in the rock phosphate is much less readily available to the crops than that in acid phosphate but the proportion is much higher, 28 per cent compared with about 15 per cent in the latter, and the cost per ton is much less, especially near the mines.

ENORMOUS DEMAND AT PRESENT

At the present time the demand for both acid phosphate and rock phosphate for use on the spring planting is so great that producers are unable to supply it promptly. The higher priced steamed bone meal, with a phosphoric acid content of 28 per cent, and this in a form practically as available as in the acid phosphate, is still to be obtained in Minnesota.

GREATER PROFITS WITH HIGH PRICES

Where phosphates have been found profitable at ordinary prices, they should be much more so now, as they have not advanced in cost to correspond with farm products.

NO LONG-TIME EXPERIMENTS IN MINNESOTA

Extensive experiments, the results of which are summarized in the tables, were started in 1914. Minnesota has no record of long-time experiments with

phosphates from which to judge of their value on her soils, altho from time to time during the forty years previous to 1914 the Agricultural Experiment Station had conducted one-year experiments either on its farm near St. Paul or in coöperation with farmers in various parts of the state—always without distinctly encouraging results.

EXTENSIVE EXPERIMENTS NOW IN OPERATION

Four years ago the Experiment Station started extensive experiments with both rock phosphate and acid phosphate at all its substation farms and at University Farm, the intention being to continue them indefinitely, each year's results thus adding to our knowledge of the possible field for these fertilizers.

The results to date indicate that at the Morris substation, and hence on the large areas of black prairie soils of which it is representative, acid phosphate will be found highly profitable when the amount of manure available is insufficient for a fair application once in the course of each rotation period of from three to five years. Not all the black prairie soils behave like those at Morris, those at Crookston and Waseca having so far shown little or no response to either of the phosphates. Even at Morris the acid phosphate appears profitable only when used without manure. However, the great acreage of land in the west central part of the state devoted to grain crops, and the totally inadequate number of livestock to provide manure for it all, lend great interest to the question as to how far to the south, east, and north of Morris similar profitable results may be secured.

Profit or Loss at the Different Farms

Table I shows the cost of the various treatments, Table II the gross profit, or increase in value of all the crops in the rotation above the cost of the fertilizers, and Tables III to VII the average yields for the last three seasons of all the crops grown in the rotations.

TABLE I. COST OF FERTILIZER AND MANURE USED IN ONE CROP ROTATION

Treatment	Four-year rotation at Morris, Crookston, University Farm, and Waseca		Three-year rotation at Grand Rapids and Duluth	
	Amount	Cost	Amount	Cost
No manure or fertilizer	.....	....	.....	....
Manure only, 40 cents per ton	8 tons	$3.20	10 tons	$4.00
Acid phosphate only, $20 per ton	480 lbs.	4.80	360 lbs.	3.60
Rock phosphate only, $10 per ton	2,000 lbs.	10.00	2,000 lbs.	10.00
Manure and acid phosphate	8 tons+ 480 lbs.	8.00	10 tons+ 360 lbs.	7.60
Manure and rock phosphate	8 tons+ 2,000 lbs.	13.20	10 tons+ 2,000 lbs.	14.00

TABLE II. GROSS PROFIT FROM DIFFERENT TREATMENTS
(Increase in value of crops in rotation above cost of fertilization*)

Treatment	Morris	University Farm	Crookston	Grand Rapids
Manure only	$8.98	$7.94	$−1.98	$31.02
Acid phosphate only	10.12	−2.06	−0.60	−1.30
Rock phosphate only	−0.42	−9.58	−12.38	−13.16
Manure and acid phosphate	7.28	7.48	−3.92	33.77
Manure and rock phosphate	2.92	−2.66	−14.70	18.57

* A minus sign indicates loss.

Data are not reported for either of the two most recently acquired substation farms, those at Duluth and Waseca, both of which came under the control of the Experiment Station late in 1913. On the Duluth farm, just cleared from the forest, experiments were initiated in 1916, the fertilizers having been applied to potatoes and rutabagas in 1916 and 1917 and to oats in 1917 only. Neither of the two phosphates has shown any definitely beneficial effects on any of these crops. While experiments were started in 1914 at Waseca, drainage was inadequate, and standing water has repeatedly caused so much injury that the data can not be satisfactorily reported in a summary form like that used in Tables III to VII. However, neither of the two phosphate fertilizers has so far caused any distinct increase in yield with any of the crops.

Present and Pre-War Prices

In computing the values of the crops, and the profit or loss from fertilization, pre-war prices have been used, namely, wheat, $1 per bushel; corn, 60 cents; oats, 40 cents; potatoes, 50 cents; hay, $8 per ton; acid phosphate, $20 per ton; and rock phosphate, $10 per ton. For the manure a cost of only 40 cents per ton has been assumed, enough to cover the cost of hauling it from the stable and applying it to the fields. The profits or losses at present prices may be easily computed from the present market quotations for the crops and a price of $25 per ton for acid phosphate and $11 for rock phosphate.

As the increase in the price of phosphates has been relatively much less than that in prices of farm products, some treatments which showed a loss at pre-war prices may show a satisfactory profit under present conditions.

TABLE III. YIELD AND VALUE OF CROPS AT UNIVERSITY FARM, ST. PAUL

Treatment	Average yield, 1915–1917				Value of four crops in rotation
	Corn	Wheat	Oats	Hay*	
	Bushels	Bushels	Bushels	Tons	
No manure or fertilizer....	41.4	26.7	64.9	2.37	$96.46
Manure only.....	47.7	29.3	68.6	2.78	107.60
Acid phosphate only.....	38.8	28.8	67.0	2.54	99.20
Rock phosphate only.....	42.9	27.9	66.1	2.10	96.88
Manure and acid phosphate	48.7	30.8	70.2	2.98	111.94
Manure and rock phosphate	47.2	29.4	67.4	2.79	107.00

* For two years only.

TABLE IV. YIELD AND VALUE OF CROPS AT MORRIS EXPERIMENTAL FARM

Treatment	Average yield, 1915–1917				Value of four crops in rotation
	Corn	Wheat	Oats	Hay	
	Bushels	Bushels	Bushels	Tons	
No manure or fertilizer....	36.0	23.1	64.9	2.07	$87.22
Manure only.....	41.9	24.9	71.4	2.60	99.40
Acid phosphate only.....	40.5	27.2	70.8	2.79	102.14
Rock phosphate only.....	37.2	24.0	68.8	2.87	96.80
Manure and acid phosphate	41.9	26.4	69.6	2.89	102.50
Manure and rock phosphate	42.2	25.7	71.4	2.97	103.34

TABLE V. YIELD AND VALUE OF CROPS AT CROOKSTON EXPERIMENTAL FARM

Treatment	Average yield, 1915–1917				Value of four crops in rotation
	Corn*	Wheat†	Oats	Hay‡	
	Bushels	Bushels	Bushels	Tons	
No manure or fertilizer	27.5	15.2	67.9	1.3	$69.26
Manure only	26.5	17.1	64.1	1.48	70.48
Acid phosphate only	25.8	18.1	67.7	1.6	73.46
Rock phosphate only	25.8	15.2	62.9	1.38	66.88
Manure and acid phosphate	30.5	17.2	62.4	1.61	73.34
Manure and rock phosphate	26.3	15.9	60.4	1.49	67.76

* For 1914, 1915, and 1916; only stover in 1917.
† For 1914 and 1917 only.
‡ For 1914, 1916, and 1917.

Rotations Include Most Important Crops

At University Farm, Morris, Crookston, and Waseca, a 4-year rotation of corn, wheat, oats, and hay (clover and timothy) is employed; while at Grand Rapids and Duluth a 3-year rotation of potatoes, oats, and hay is used. At Crookston and University Farm, only half of each plot is devoted to corn, the other half being planted to potatoes. At Duluth rutabagas take the place of corn, and at Grand Rapids each plot is divided among potatoes, rutabagas, and corn. At these farms the manure and phosphates are applied to the land as it is being prepared for the cultivated crop. At Crookston, clover and timothy are seeded with wheat, but at the other farms with oats.

TABLE VI. YIELD AND VALUE OF CROPS AT GRAND RAPIDS EXPERIMENTAL FARM

Treatment	Average yield 1915–1917			Value of three crops in rotation
	Potatoes	Oats	Hay	
	Bushels	Bushels	Tons	
No manure or fertilizer	137.1	36.8	1.24	$93.19
Manure only	199.3	43.4	1.4	128.21
Acid phosphate only	141.7	37.8	1.19	95.49
Rock phosphate only	129.1	38.5	1.26	90.03
Manure and acid phosphate	206.4	46.2	1.61	134.56
Manure and rock phosphate	195.2	43.8	1.33	125.76

TABLE VII. YIELD OF POTATOES AT UNIVERSITY FARM AND CROOKSTON AND GROSS PROFITS FROM DIFFERENT TREATMENTS WHEN POTATOES WERE RAISED IN THE PLACE OF CORN IN THE 4-YEAR ROTATION

Treatment	Yield per acre		Increase in value of four crops in rotation above cost of manure and fertilizers*	
	University Farm	Crookston	University Farm	Crookston
	Bushels	Bushels		
No manure	90.2	81.5	.....	.....
Manure only	144.4	99.6	$31.27	$7.67
Acid phosphate	111.1	104.2	9.95	1.77
Rock phosphate	92.7	91.2	−9.23	−6.51
Manure and acid phosphate	142.0	104.1	29.00	5.58
Manure and rock phosphate	136.0	90.5	16.76	−9.48

* A minus sign indicates loss.

Representative Soils on the Different Farms

On the Morris and Waseca plots the soil is a black silt loam with a silt loam subsoil, similar in appearance to the prevailing types of black prairie soils in the western, southwestern, and south central counties of Minnesota. At Crookston the plots are on black clay loam, or "gumbo," with a clay loam subsoil, the soil so characteristic of a large part of the Red River Valley. At Grand Rapids the soil is a light colored sandy loam with a subsoil similar in texture, while that at Duluth is a stony clay loam with a stony red clay subsoil. At all of these farms the soil on the plots is simliar to that of the most extensive types found in the surrounding districts. The soil at University Farm, a dark silt loam with a silt loam subsoil underlaid at a depth of from 3 to 4 feet by a thick gravel bed, unfortunately represents a type of only very limited extent. At all six farms the soils are so well supplied with lime that applications of ground limestone at the rate of three tons per acre have so far failed to produce any distinctly beneficial effect, even on clover.

Numerous Small Plots Used

All the plots are one-tenth acre in size but, as already mentioned, on those farms where two cultivated crops are grown, half of the plot is devoted to each.

For the six treatments indicated in the tables, 72 plots are employed on each of the four farms with a 4-year rotation; and 54 plots on the two farms with a 3-year rotation, thus every year giving 18 plots to each crop and 3 plots to every treatment of each crop. In the tables the averages of all three plots for each crop, or of nine separate yields in all, are reported.

Manure Used Alone Profitable

From Table II it will be seen that manure used alone has proved profitable on all the farms except that at Crookston, and on this when potatoes were included in the rotation. The use of either rock phosphate or acid phosphate as a reinforcement has been found unprofitable at all the farms except that at Grand Rapids, where reinforcement with acid phosphate has caused a slight increase in profit.

Reinforcement of Manure Unprofitable

This lack of profit in reinforcement of manure with phosphates is confirmed by the results of a simple experiment conducted at University Farm since 1906, these being summarized in Table VIII. On this a 3-year rotation of corn, oats, and clover has been employed with a single plot of each crop each year, except in the case of the check or untreated plot, with which there were duplicates. The yields show no definite increase from the reinforcement with either of the two phosphates.

TABLE VIII. EFFECT OF REINFORCING MANURE WITH PHOSPHATE AT UNIVERSITY FARM ON A 3-YEAR ROTATION OF CORN, OATS, AND CLOVER. AVERAGE YIELDS FOR 6 YEARS, 1909-1914*

Plot	Treatment	Corn	Oats	Hay
		Bushels	Bushels	Tons
4	No manure or phosphate	52.5	60.8	2.74
5	Six tons of manure for each rotation	57.9	61.6	2.89
12	Six tons of manure for each rotation	57.7	64.4	2.71
10	Six tons of manure and 1,000 pounds of rock phosphate for each rotation	58.5	64.9	2.85
11	Six tons of manure and 400 pounds of acid phosphate for each rotation	58.1	65.8	2.91

* Arny, A. C. Rotation investigations. Minn. Agr. Exp. Sta. Bull. 170. 1917.

Rock Phosphate Not Profitable

Rock phosphate used alone shows a loss at all the farms, but at Morris the beneficial effect has been so marked that within another year or two it is probable that increased yields resulting from the large amount remaining in the soil will cause this treatment to show a profit. The application of this fertilizer will be repeated only at the end of the second rotation period, and hence the cost of it will be chargeable against eight crops instead of four, as in the case with the acid phosphate, which is applied at the end of each rotation period.

Acid Phosphate Profitable Only at Morris

When corn was used as the cultivated crop in the rotation, acid phosphate was profitable only at Morris; at the other farms it cost more than the increase in crops was worth. When potatoes were employed, it was profitable at University Farm also.

First Season's Results Unfavorable

Altho the experiments were started in 1914, the data in the tables with the few exceptions indicated by footnotes, are for only the last three seasons—1915, 1916, and 1917. At Morris in 1914, hail, defective drainage on part of the plots, and other causes, so affected the crops on many of the plots that no distinctly beneficial effects of the phosphate were shown by the yields, and so to make the data from all the other experimental farms comparable with those at Morris the yields in only the last three seasons have been employed in computing the averages for the different crops. At University Farm, Grand Rapids, and Crookston, in 1914, the phosphates showed even less beneficial effects than in the following years. If the experiments had been then discontinued, the results of the earlier one-year experiments would have been fully confirmed.

Details Published by Substations

Details of the experiments, giving yields on each plot in each year, have in part been already published, those for Crookston for the first three years being given in the Report of the Superintendent of the Northwest Experiment Station for 1910 to 1916; those for 1915 and 1916 at Grand Rapids in the Report of Progress of Work at the North Central Experiment Station; those for the four years at Morris in the Report of the West Central Substation for 1917; and those at Duluth in 1916 in the Report of the Northeast Demonstration Farm and Experiment Station. The reports may be obtained free by writing the superintendents of the respective substations.

QUANDARY OF SOUTHWESTERN MINNESOTA FARMERS

In view of the exceptional response of phosphate fertilizers at Morris, it is of especial interest to the farmers of southwestern Minnesota to know what results have been obtained to the south of the Minnesota line on soils of similar origin and similar appearance. The only experiments reported on these are those from the Iowa Agricultural Experiment Station farm at Ames, in which a 4-year rotation of corn, corn, oats, and clover has been used, applying both the manure and the phosphate just preceding the first corn crop of each rotation. Steamed bone meal applied at the rate of 800 pounds per acre has been used as the phosphate fertilizer. This contains about three times as much phosphorus as the 480 pounds of acid phosphate used at Morris, while the degree of avail-

ability is much the same. The results reported in Table IX show that the phosphate has been almost without effect, thus corresponding to the results at Waseca rather than to those at Morris. Hence the farmers in southwestern Minnesota have no satisfactory experimental results to guide them. They might secure a profit from acid phosphate alone, as at Morris, or they might lose money on the transaction, as at Ames and Waseca. The need of experimental fields in that part of the state thus becomes urgent.

TABLE IX. RESULTS OF EXPERIMENTS WITH MANURE AND PHOSPHATE AT AMES, IOWA, ON A 4-YEAR ROTATION OF CORN, CORN, OATS, AND CLOVER. AVERAGE YIELDS FOR 8 YEARS, 1906-1913*

Treatment	Corn	Oats	Hay
	Bushels	Bushels	Tons
No manure or fertilizer	60.2	55.0	2.25
Manure only, eight tons in four years	72.4	61.9	2.82
Phosphate only, 800 pounds bone meal in four years	59.1	57.9	2.45
Manure, eight tons, and phosphate, 800 pounds	72.1	62.4	2.85

* Stevenson, W. H., Brown, P. E., and Forman, L. W. Maintaining fertility in the Wisconsin drift soil area in Iowa. Iowa Agr. Exp. Sta. Bull. 161. 1915.

THE PROBLEM IN SOUTHEASTERN MINNESOTA

While the southeastern counties of Minnesota are underlaid with limestone and this rock is exposed in most of the valleys, giving the valley soils an abundance of lime, the soils of the uplands are in general much more poorly supplied with lime than are those to the west and northwest. This low-lime area may be roughly defined as the triangle bounded on the northeast by the Mississippi River, on the west by a line drawn south from St. Paul to the Iowa border, and on the south by the Iowa line. On the upland soils of this area it is usually necessary to make an application of lime or ground limestone in order to secure a successful stand and growth of alfalfa. The Experiment Station has no experimental farm or field in this highly developed portion of the state, and hence no satisfactory site for the necessary experiments. The soils of this portion appear much more similar than those of the rest of the state to soils of Illinois, Indiana, and Ohio on which phosphate fertilizers have been found highly profitable, especially when used to reinforce farm manures.

This similarity made it appear probable that phosphates would prove beneficial, and for this reason coöperative experiments with farmers in Goodhue, Olmstead, Winona, Mower, and Fillmore counties were started in the spring of 1917. Acid phosphate was applied at the rates of 200 and 400 pounds per acre, on fourteen fields of small grains and on fifteen fields of corn. On each field six 1-acre plots were brought under experiment, two being given 200 pounds of phosphate per acre, two 400 pounds per acre, and the other two receiving no fertilizer. A member of the Experiment Station staff applied the fertilizer and was present at harvest. The corn was so badly injured by the early frost that no satisfactory data on this crop were secured. With the small grains, for which the weather was very favorable, the phosphate plots gave in general somewhat higher yields, but the increase was not nearly sufficient to cover the cost of the fertilizer. The fields are to be kept under observation and the yields on the different plots are to be determined in the seasons of 1918 and 1919. The yields on the treated plots in these seasons may be sufficiently increased to make the total increase during the three years much more than cover the cost of the fertilizer. However, the results to date are

not such as to justify any general recommendation of the use of phosphates to the farmers of the southeastern counties.

DO PHOSPHATES HASTEN THE RIPENING OF CORN?

It has long been recognized that phosphates hasten the maturity of small grains by some days, and it is often claimed that they would cause corn to ripen so much earlier in Minnesota that their use would prove especially desirable with this crop in unfavorable seasons. In the last four years the corn crop at the various experimental farms has suffered much from early frosts, and in no case has any important difference been found in favor of the plots which had received phosphates, while in most instances no difference at all in ripeness was discernible.

PHOSPHATES ON PEAT SOILS

On peat soils, other than those with the peat layer so thin that plant roots readily pass through it and obtain from the underlying clay or loam the forms of plant food in which peats are deficient, the application of a phosphate, either alone or in combination with potash, with lime, or with potash and lime together, is usually necessary in order to secure any satisfactory crops. As to whether the treatment will prove profitable will depend chiefly on the cost of the lime and potash.

GARDEN AND TRUCK CROPS

With truck crops, the cost of an application of phosphate in comparison with that of the large amount of labor is so small that if only a very moderate increase in yield were caused by the fertilizer its use would be profitable.

SANDY AND RED DRIFT SOILS NOT INCLUDED IN EXPERIMENTS

Extensive areas of sandy soils north and northwest of the Twin Cities, and occupying large portions of Anoka, Isanti, Sherburne, Crow Wing, and Wadena counties, are as yet represented by neither experimental farm nor experimental field. The same is true of the Red Drift soils, loams, clay loams, etc., all with a red loam or a red clay loam subsoil, which occupy most of Kanabec, Mille Lacs, Benton, Morrison, and Crow Wing counties as well as parts of the counties adjacent to these. Accordingly, the results of the experiments reported may not be at all applicable to the sandy and Red Drift soils.

SUMMARY

The results of the experiments so far conducted in Minnesota on the use of phosphate fertilizers on ordinary, or mineral soils, and with the ordinary farm crops, do not justify any recommendations for their general use even under the prevailing high prices. However, the highly profitable results shown at the Morris experimental farm, when acid phosphate was used alone, suggest that on a large proportion of those soils in the west central part of the state upon which grain has long been grown without the application of manure, the use of acid phosphate may be found highly profitable with wheat and clover on the fields which do not receive an application of manure once every three to five years. On peat soils and with truck crops the conditions are so different that the above remarks are not intended to apply to them, while with the soils of the sandy and Red Drift areas there have been no experiments.